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Technology Forecasting in Fisheries Sector: Cross Impact Analysis and Substitution Modeling

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SUMMARY

Fisheries sector in India has made giant strides in recent years and its role in increasing food supply, generating job opportunities, raising nutritional level and earning foreign exchange need hardly be emphasized. Its future is likely to be much different from what it is now. New upcoming technologies and resources are expected to be different from what these are now which would require reconciliations of conflicting socio-economic and environmental objectives and trade-offs. Significant development in fisheries has been made possible by technological progress and policy changes. However, in the context of increasing globalization and emergence of new markets, the future of Indian fisheries is bound to be influenced. It is therefore imperative to articulate technological needs of different aspects of fishing and fish processing and contemplate how developments in science and policy can help to address these needs. For this, applications of two chief tools from the field of Technology Forecasting (TF) have been employed in the domain of fisheries. Of the TF tools available, two techniques viz., Cross Impact Analysis (CIA) technique and Substitution modeling were attempted in the field of fisheries. One of CIA techniques viz., Kane's simulation model was employed to study the long-term dynamics of production (marine), imports and exports of Indian fish commodities. In addition, by considering global production of *P. vannamei* shrimp species and other shrimp species over time, substitution models viz., Pearl and Gompertz were fitted to ascertain the time period required for the emerging species to replace the traditional ones. The analogy between the CIA model used and substitution models are also explained. To sum up, it has been demonstrated that TF can give incisive insights that can aid decision makers to plan strategies in transforming expected outcomes to preferred futures.

Keywords: Kane's simulation modeling, Gompertz model, Pearl model, Foresight, *vannamei* shrimp.

1. INTRODUCTION

Technology is nothing but the totality of the means employed to provide aids necessary for human sustenance and comfort. Forecasting is the process of computation/prediction or giving a statement of what is expected to happen in the future in relation to a particular event or situation. A technological forecast is a prediction of the future characteristics of useful machines, procedures or techniques (Martino 1983). Reliable and long-range Technology Forecasting (TF) provides important and useful inputs for proper, farsighted and informed planning, more so, in the context of fisheries, which is full of uncertainties. The area of TF can be put to effective use for predicting the key features of technologies (both tangible ones like machines, devices etc. to intangible ones like methodologies, processes, best management practices etc.) in the domain of fisheries. TF has sprung up as an evolving field that involves an explicit recognition about the choices made today leading to shaping or creating the desired future. TF is distinct from the usual forecasting where technology plays a role but not the central issue (Roper *et al.* 2011).

Of late, TF is considered as a part of the whole gamut of what is called, Technology Foresight which is more than just forecasting technological trends and needs, consisting of the following stages: Framing - Scoping the domain of study, Scanning - Gathering relevant information, Forecasting- Describing most likely and alternative futures, Visioning - Choosing a preferred future, Planning - Organizing to achieve the vision and lastly, Acting - Implementing the plan (Hines and Bishop 2013). Technology Foresight thus involves systematically attempting to look into

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the longer-term future of science, technology, the economy, the environment and society with the aim of identifying the areas of strategic research and emerging generic technologies likely to yield the greatest economic and social benefits (Georghiou *et al.* 2008). In addition, the factors influenced by Social, Technological, Economic, Environmental, and Political (STEEP) environments should also be considered in foresight exercises; adding Information and Legal, it becomes EPISTLE with again the Social domain further divided into the Demographic and Cultural domains. Technology Foresight activity can thus help envision facilitating action upon alternative possibilities of possible, to plausible, and further, leading to probable, ultimately ending with preferable futures.

It is not an overstatement that fisheries in India is a sunrise sector and hence its role in increasing food supply, generating job opportunities, raising nutritional level and earning foreign exchange is going to be manifold in future. Nevertheless, its upcoming scenario is likely to be much different from what it is now. New upcoming technologies and resources are expected to be different from what these are now which would require reconciliations of conflicting socio-economic and environmental objectives and trade-offs. Significant development in fisheries has been made possible by technological progress and policy changes such as efficient craft/ gear techniques, cage culture, disease diagnostic kits, nano particle coated paints, non-thermal processing/ preserving/ packaging technologies, responsible culture and capture fishing, etc. (Jeeva *et al.* 2013). However, in the context of increasing globalization and emergence of new markets, the future of Indian fisheries is bound to be affected. Rapid developments in scientific fields like Information and Communication Technology (ICT), biotechnology, remote sensing technology etc., undoubtedly have profound applications in fisheries development and its management. It is therefore imperative to articulate technological needs of different aspects of fishing and fish processing and contemplate how developments in science and policy can help to address these needs. This calls for application of tools in the domain of fisheries from the field of TF.

Few studies have been conducted for TF in the domain of agriculture in India. Rohatgi *et al.* (1979) have forecasted the technological needs and trends in different sectors including Food and Agriculture using various TF approaches. Rao *et al.* (2000) have forecasted the Oilseeds scenario using Delphi, Brainstorming and other TF methods. A good account of applications of TF in agriculture and allied fields are given in Ramasubramanian *et al.* (2014, 2015).

Of the TF tools available, two techniques viz., Cross Impact Analysis (CIA) and Substitution modeling were attempted in the field of Indian fisheries. Here CIA technique was employed to study the long-term dynamics of production (marine), imports and exports of Indian fish commodities. By considering global production of *P. vannamei* shrimp species vis-à-vis other shrimp species over time, substitution models viz., Pearl and Gompertz were fitted to ascertain the time period required for the emerging (read relatively new) species to replace the traditional (read other existing species) ones.

In this paper, while Section 1 dealt with introduction and brief review of literature on TF, Section 2 deals with the materials and methods including review on CIA and substitution modeling, Section 3 give results and discussion of the study and finally it is concluded in Section 4.

2. MATERIALS AND METHODS

Realistic problems involve a multiplicity of competing variables, presenting a complexity of behavior that usually dwarfs human capacity for comprehension. Consequently decisions are usually made in truncated spaces by sharply reducing the variables that are involved. Cross impact analysis (CIA) method is one of the expert opinion based techniques (like the most popular Delphi technique) that can be utilized for technology forecasting. This method was developed to overcome some of the demerits of other existing methods on experts' opinions. A potential shortcoming of Delphi (as well as many other forecasting techniques) is that interrelationships (referred to as cross-impacts) among events shaping the future are difficult to consider explicitly. Cross-impact method utilises certain subjective information (in terms of probabilities or impact values) as part of the procedure in order to obtain forecasts. When dependencies are suspected among future events, the chance probability (or in some studies the level) that a potential development will actually occur is influenced by the occurrence or non-occurrence of related developments. The cross-impact method estimates each development's level (or probability) of occurrence based on interrelationships that exist between events included in the analysis over a period of time in the long run. A good account on cross impact analysis are given in Gordon and Hayward (1968), Sullivan and Claycombe (1977), Helmer (1983) and Porter *et al.* (1991). The advantages of the cross-impact method are its ability to take interactions among events into consideration and its systematic organization of data regarding a large number of possible outcomes into an easy-to-analyze format.

For employing CIA technique, Kane's (2002) cross impact simulation (KSIM) model was utilized to infer about future behaviour of four variables of Indian fisheries viz., Marine production, Penaeid shrimp production, Marine export and Fish import over time. As culture fisheries statistics were not available separately, the production of Penaeid shrimp has been used as a proxy for aquaculture as it mainly targets high value exports. For this, time series data of these variables over the years 1962-2014 have been used, where available; while marine exports data were available for this entire period, continuous data on marine fish production of India were available from 1979 only; Penaeid shrimp production was available from 2000 onwards. Fish imports were obtained for the period 1989-2009 and projected figures were used till 2014 by resorting to simple regression on time. The data for the recent years are given in Table 1. Except imports, whose data have been taken from FAO (2009), the remaining data were taken from Handbook of Fisheries Statistics (2014). The initial values of these four variables were determined as a fraction (a number between 0 and 1) by dividing the latest figures with the corresponding assumed maximum that could be attained by these variables (see third row from last in Table 1). Thereafter, the impacts of each variable on another (on a pairwise basis) were determined by finding the regression coefficients (Table 2) of the simple linear regressions of each of the variable upon each one of the other variables. These coefficients were converted into a -3 to +3 scale by transformation and judgment (Table 3). For doing this, the coefficients were transformed into impact levels viz., 1, 2 and 3 based on whether their values lie in the range 0 to 0.5, 0.51 to 1.5, >1.5 respectively. Here these impact levels were given negative signs whenever one of the two pairwise variables considered was import variable. It is emphasized here that an exogenous variable (which subsumes factors such as R&D, government policy, extension etc.) was also considered which would impact these variables (at the same time will not be impacted upon by these variables), appearing in the last column of Table 3.

The KSIM model under CIA technique is given by

$$x_i(t+\Delta t) = \{x_i(t)\}^{pi(t)} \quad (1)$$

where $x_i(t)$ is the i-th variable (here, economic parameter) at time t (i = 1, 2, ..., N) and $x_i(t+\Delta t)$ is the same variable, after an incremental time period Δt; $p_i(t)$ is the probability like measure which is a function of the direct and indirect impacts of all other variables $x_j(t)$ $j\neq i$ on $x_i(t)$ where $p_i(t)$ is given by

$$p_i(t) = \frac{1+\frac{\Delta t}{2}\sum_{j=1}^{N}(|a_{ij}|-\alpha_{ij})x_j(t)}{1+\frac{\Delta t}{2}\sum_{j=1}^{N}(|a_{ij}|+\alpha_{ij})x_j(t)} \quad (2)$$

with α_{ij} as the impact of x_j on x_i(i, j = 1,2,..., N). That is $p_i(t)$ can also be written as

$$p_i(t) = \frac{1+\Delta t(\text{sum of negative impacts of } x_j \text{ on } x_i)x_i(t)}{1+\Delta t(\text{sum of positive impacts of } x_j \text{ on } x_i)x_i(t)} \quad (3)$$

For fitting substitution models, data on production of global *L. vannamei* shrimp species (Table 6) has been considered for the study (Anderson 2015). Efforts were made to collect the same for India, but could not be obtained. It is pertinent to state here that the global trend is nothing but the Asian situation and, at the same time can be considered as mimicking the Indian scenario as well.

Two substitution models viz. Pearl and Gompertz were considered. It can be shown mathematically that Pearl model is equivalent to the Fisher-Pry model usually used in technology forecasting studies (Porter *et al.* 1991).

$$\frac{y_t}{L} = \frac{1}{2}[1+\tanh\{g(t-t_0)\}] \quad (4)$$

where t_0 is time for 50% substitutions, y_t is study variable at time t and L is the maximum attainable value of y_t, which is nothing but the usual logistic growth model by letting $x = g(t-t_0)$ and using

$$1+\tanh x = 1+\frac{e^x-e^{-x}}{e^x+e^{-x}} \quad (5)$$

Thus using equation (5) in equation (4), the following model is obtained (henceforth referred to as Pearl model)

$$y = \frac{L}{1+a\, e^{-r\,t}} \tag{6}$$

where $a = e^{2gt_0}$ and $r = 2g$.

Thus, henceforth considering equation (6), a is the function of y at initial time period and r is the growth rate. For fixed L, the values of r and a were estimated by non-linear fitting i.e. by fixing r, the initial value of 'a' was calculated as (taking y_t for a particular value of t)

$$a = e^{r\,t}\left(\frac{L}{y_t} - 1\right) \tag{7}$$

The second model i.e. Gompertz model is given by

$$y = L\, e^{-a\, e^{-r\,t}} \tag{8}$$

with initial value for 'a' calculated as

$$a = e^{rt}\log\left(\frac{L}{y_t}\right) \tag{9}$$

It is noted here that, for both the models, the initial value of 'r' was obtained as an average of the simple year-to-year growth rates of the available data. Fixing this r value, the value of 'a' was obtained (for each model separately using its corresponding formula i.e. equation (7) or (9)) by taking any particular time period t within the available data period and its corresponding value y_t and also taking L as 100% i.e. the maximum saturation level or ceiling value (note that in the usual statistical modeling, for logistic model, L is also estimated rather than assumed as fixed). While Pearl curve is symmetrical about the inflection point at $t = \ln(a)/r$ when $y = L/2$, the Gompertz curve is not so and its inflection point occurs at $t = (\ln a)/r$ when $y = L/e$. The slope of the Pearl curve involves y and $(L\text{-}y)$, i.e., distance already come and distance yet to go to the upper limit, while, for large values of y, the slope of the Gompertz curve involves only $(L\text{-}y)$, i.e., is a function only of distance to go to the upper limit (Porter *et al.* 1991).

3. RESULTS AND DISCUSSION

The maximum attainable values of each of the economic parameters (Table 1) have been arrived at both by judgement and also considering the existing trends and future possibilities which are discussed subsequently. The maximum marine production has been considered as 5 million tonnes (mt), as it has been reported that the potential of marine fisheries is 3.9 mt and has been revised thereafter as 4.54 mt (Rao 2011). About 0.5 mt has been added to this value to make it 5 mt to give allowance for its possible increase owing to cage culture technology fast picking up in marine environment (mariculture). The Penaeid shrimp production comes roughly two-thirds from culture and the rest from capture, more so, because not only brackish waters, but also inland salt waters are also brought into shrimp culturing now-a-days. Hence a conservative figure of 0.55 mt has been fixed as maximum for Penaeid shrimp production. The marine exports production has been kept to more than around one and half times to the present figure to arrive at the maximum, also accounting for the possible export potentiality of the increasing aquaculture production scenario. As India for a long time in reality exercised an import ban, through high tariffs and complicated licensing schemes (Trollvik 2002), the level of imports was very low at least during pre-liberalization period. However, there has been an increase from 1994 onwards, but the quantity is still very low. The present imports are expected to increase three-fold owing to increased liberalization and pressure to decrease the high import tariffs currently prevalent hence it has been fixed at 0.15 mt.

Table 1. Indian fisheries economics data (in Million tonnes)

Year	Marine production	Penaeid Shrimp production	Marine exports	Fish imports
2003	2.99	0.16	0.47	0.06
2004	2.94	0.20	0.41	0.05
2005	2.78	0.20	0.46	0.05
2006	2.82	0.41	0.51	0.03
2007	3.02	0.28	0.61	0.03
2008	2.92	0.27	0.54	0.02
2009	2.98	0.29	0.60	0.03
2010	3.10	0.29	0.68	0.03
2011	3.25	0.31	0.81	0.03
2012	3.37	0.33	0.86	0.04
2013	3.32	0.32	0.92	0.04
2014	3.43	0.32	0.98	0.04
Assumed maximum	*5.00*	*0.55*	*1.60*	*0.15*
Recent (2014) upon maximum	0.69	0.59	0.61	0.27
Initial value	0.7	0.6	0.6	0.3

Note: Initial values are nothing but recent upon maximum values correct to one decimal place.

Table 2 gives the values of regression coefficients obtained by fitting various two-variable (simple) linear regression models. The data values for both the variables under consideration are fractions less than one (also greater than zero) owing to the fact that these values are nothing but ratios obtained by dividing with the maximum attainable ceiling value for the corresponding economic parameters considered; hence, even though regression coefficients can lie between $\pm\infty$ on the real line, it can be seen that the coefficients are around one only. As discussed previously in Section 2, Table 2 was utilized for computing the cross impact levels of the economic variables and has been given in Table 3 as a 4×4 matrix (excepting the last column of Table 3 pertaining to exogenous factor, which has been populated purely based on qualitative judgement).

Table 2. OLS regression coefficients of simple linear regression of one variable on another after taking ratio of data values over the corresponding assumed maximum values

	Marine production	**Penaeid Shrimp production**	**Marine exports**	**Fish imports**
Marine production	-	0.18	0.68	0.47
Penaeid Shrimp production	1.42	-	0.64	-0.39
Marine exports	1.13	0.65	-	0.97
Fish imports	1.11	-0.15	0.50	-

Note: 0.68 is regression coefficient of 'marine production' on 'marine exports' and so on.

It can be seen in Table 3 that penaeid shrimp production is negatively affected by fish imports but has positive impacts by marine production and export; so are the cases with marine production and marine exports. However, in contrast, fish imports are having negative influences from all other economic parameters under consideration. It is mentioned here that the present levels of the economic parameters are nothing but the initial values given in Table 1 converted into percentages. Thus, for marine production, still there is a scope of enhancing till 30% over and above the existing level to reach saturation, if the same technological endowments are prevailing in future as well; likewise a scope of 40% each for penaeid shrimp production and marine exports and of 70% for fish imports. Also it is worth mentioning that Table 3 should be read as: impact value is '1' of penaeid shrimp production (in column) on marine production (in row) on a 1 to 3 scale; likewise for other economic parameters considered pairwise. Hence the direction of impacts is from column to row. For impacts of exogenous factor on the economic parameters, a conservative impact value of 1 is given for both marine and penaeid shrimp production, while a value of 2 is given for exports aiming to boost them in future and an impact value of (-1) for imports is given to curb the same. Hence it can be seen that CIA technique is a quasi-quantitative technique involving subjective knowledge as well.

Table 3. Cross impact matrix for CIA technique –Fisheries scenario in India

	Present level	**Impact of x_j on x_i (i.e. a_{ij})** [*Direction of impact is indicated on the left*]				
		Marine Production	**Penaeid Shrimp production**	**Marine exports**	**Fish imports**	**Exogenous factor**
Marine Production	70% (x_1)	0	1	2	-1	1
Penaeid Shrimp production	60% (x_2)	2	0	2	-1	1
Marine exports	60% (x_3)	2	2	0	-2	2
Fish imports	30% (x_4)	-2	-1	-1	0	-1

Table 4. Coefficients for computation of negative cross impacts sum in Equation (2 & 3)

	Marine Production	**Penaeid Shrimp production**	**Marine exports**	**Fish imports**	**Exogenous factor**
Marine Production	0	0	0	1	0
Penaeid Shrimp production	0	0	0	1	0
Marine exports	0	0	0	2	0
Fish imports	2	1	1	0	1

Table 5. Coefficients for computation of positive cross impacts sum in Equation (2 & 3)

	Marine Production	Penaeid Shrimp production	Marine exports	Fish imports	Exogenous factor
Marine Production	0	1	2	0	1
Penaeid Shrimp production	2	0	2	0	1
Marine exports	2	2	0	0	2
Fish imports	0	0	0	0	0

The cross impact values α_{ij}'s of equation (2) given in Table 3 were then utilized to find negative and positive impacts using Microsoft Excel which are given in Tables 4 and 5 respectively for computation of their sums in equation (2). The Kane's simulation model of CIA given in equation (1) was fitted with the initial values of $x_i(t)$'s as given in second column of Table 3. Thus the initial $p_i(t)$'s in equation (2) are computed as 0.97568, 0.96815, 0.96176 and 1.036 using values given in Tables (3) through (5). It is noted here that as $p_i(t)$'s are probability like measures as already stated while explaining equation (1), hence they do not adhere to the limits of probability and some values can exceed one but will not be far from one. Perusal of Tables 4 and 5 reveal that, if a cell position has a non-zero value in Table 4, then it will have a zero value in Table 5 and vice versa (unless they are in the diagonal positions of the 4×4 matrix ignoring the last column).Taking Δt as an infinitesimally small quantity 0.01, thereafter, the values of $x_i(t)$'s are updated by the equation (1) by taking power of their initial values with these corresponding $p_i(t)$'s. In this way, the consecutive values of $p_i(t)$'s and $x_i(t)$'s are computed and the results obtained are plotted in Fig. 1. It can be inferred from Fig. 1 that, in the long run, all the three variables viz. marine production, marine export and penaeid shrimp production show increasing trend while fish imports show rapid decreasing trend. It can also be observed that the total marine exports show sustained growth in the long run due to positive influence by penaeid shrimp production (which is increasing at an increasing rate) and marine production (increasing at a slightly decreasing rate) at the same time these three variables attain saturation. It can also be seen that, even though the penaeid shrimp production share is at present lower than that of marine production when the saturation level is considered as 100% in both cases, as time progresses, the former will be contributing more to the latter, if the same scenario continues.

In general, in India, owing to self-sufficiency in fish resources and under-exploited deep-sea resources in our waters, fish imports are discouraged by means of high import tariffs. Thus it was inferred from the study that if curbs continue to be imposed on imports from the government side then it will drastically reduce imports in the long run. Also, in the business-as-usual scenario, shrimp production's share will more of augment the marine production basket in the long run, due to the direct (when considered pairwise) and also the indirect impacts (through the cross impact model) of the economic parameters in question (Fig. 1).

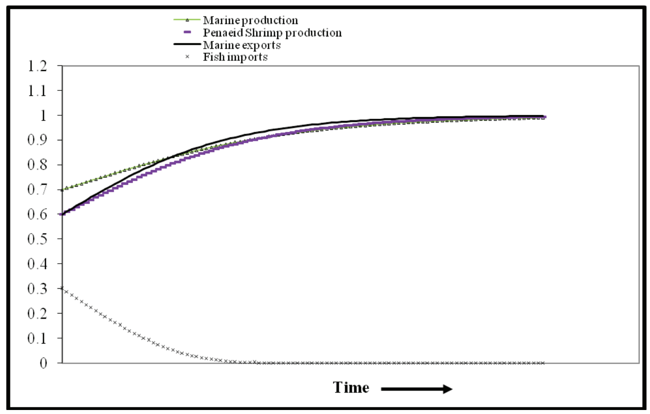

Fig. 1. CIA technique – Indian Fisheries Scenario

Application of the second TF tool employed i.e. substitution modeling in global shrimp production is discussed subsequently. Aquaculture contributes significantly to the overall fish production globally. Shrimp farming has been given a fresh lease of life by introduction of Pacific White Shrimp species *L. vannamei* (*Krishnan et al.* 2011). The advent of Specific Pathogen Free (SPF) brood stock and the inherent attributes of *L. vannamei*, along with advances in its culture technology, have made mind-boggling production possible at very low costs. As against this, high production costs, diminishing selling prices, the absence of quality seed, high incidence of disease leading to frequent failures have made *Penaeusmonodon* (Black/ Giant tiger) shrimp species unviable. Hence *L. vannamei* has over time got clear and significant advantages in higher and reliable production over other shrimp species.

Frequently, one is interested in forecasting the rate at which a new technology (here, *L. vannamei*) will be substituted for an older technology (here, other shrimp species) in a given application. Substitution of new technology for an older one often exhibits a growth curve. Initially, the older technology has the advantage. Initial rate of substitution of new technology is low. The older technology is well understood, its reliability is probably high, users have confidence in it, and both inputs and expertise are readily available while in the initial stages, the new technology is unknown and its reliability is uncertain and inputs are hard to obtain and skilled expertise scarce. As the initial problems are solved, the rate of substitution increases. As the substitution becomes complete, however, there will remain few applications for which the old technology is well suited. The rate of substitution slows, as the older technology becomes more and more difficult to replace (Porter *et al.* 1991).

Table 6. Global share of *L. vannamei* species in Shrimp aquaculture production (in million tonnes)

Year	*L. vannamei* Production	Total Shrimp Production	% Share
1991	0.15	0.90	16.67
1995	0.15	1.10	13.64
2000	0.16	1.30	12.31
2005	1.75	2.90	60.34
2010	2.80	3.90	71.79
2013	2.40	3.60	66.67
2014	2.80	3.80	73.68
2015	3.00	4.00	75.00

Source: Anderson (2015)

The substitution models Pearl and Gompertz considered in this study which have been already described in Section 2 were fitted to data on share of *L. vannamei* in global shrimp aquaculture production. The models considered were non-linear, hence iterative method of approximate least squares fitting was resorted to (Draper and Smith 1998). To start the iteration, initial values of *a* and *r* were obtained as discussed previously. The models were fitted using 'Solver' option in Microsoft Excel and results given in Table 5.

Among the two models, Pearl and Gompertz, Gompertz model came out to be the best for the data under consideration in terms of minimum residual sum of squares (Table 5). The plot of actual versus fitted data (Fig. 2) also revealed that Gompertz curve is near to actual data points in most of the cases. Thus, choosing and using fitted Gompertz model, it can be stated that, if the same trend continues, all of shrimp production which will be coming from the single species *L. vannamei* will reach saturation by the year 2035, in the *ceteris paribus* condition. However, it should be kept in mind that such a scenario will have a less chance of occurrence, due to interventions in the intervening period because of factors such as emergence of a totally new technology, hindrance to the present technology, government policy etc. Hence instead of saturation phase leading to complete dominance of one species, a new era may unfold which will mask the prevailing technology unfolding a different scenario leading to a series of such elongated 'S' curves over the future horizon.

Table 7. Parameter estimates and goodness of fit statistics for the substitution models

Model	Initial Values		Final Estimates		Residual sum of squares
	a	*r*	*a*	*r*	
Pearl	6.81	0.08	15.18	0.18	1494.31
Gompertz	2.18	0.08	4.09	0.11	1485.58

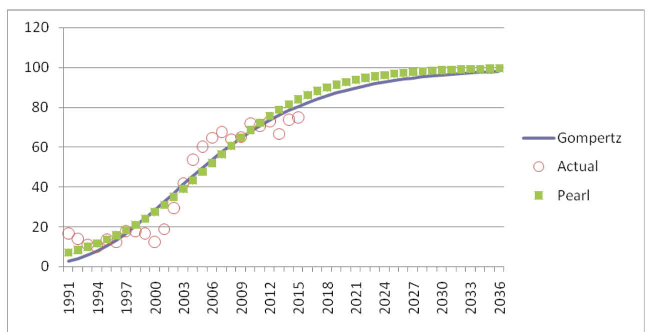

Fig. 2. Pearl and Gompertz modeling of percent share of L. vannamei in global shrimp aquaculture production

L. vannamei is a native species of the western Pacific coast of Latin America, which was introduced to Asia during the late 1970's on an experimental basis. It established itself in the new environment so well in India that it replaced *P. monodon* in the commercial market as the dominant species due to its superior aquaculture traits (Liaoand Chien 2011). The huge economic and social loss caused to the nation by the collapse of the *P. monodon* market due to WSSV virus was unpredictable at a critical phase and led to the transitional period of replacement of *P. monodon* by *L. vannamei* which witnessed a complete change in standardized technology in farming as well as certain modifications in its supply demand. Thus as a preventive measure to avoid history repeating itself, intensification of mono-species culture should be controlled and monitored while simultaneously adopting diversification of species. Potential problems that can affect future global production of *L. vannamei* include: decreasing genetic diversity through domestication and selection; increasing trans-boundary movements between continents, emergence of new and location-specific viral and other microbial diseases etc. Thus by keeping the above potential possibilities which can unfold in future to cause havoc in the sector, the policy makers of India should legislatively intervene in the production system for a secure future.

Having used Gompertz model by choosing it on the basis of minimum residual sum of squares, some additional points are worth mentioning here. From the standpoint of statistical validity, the residuals from the chosen model were tested for their independence, normality and homoscedastic variance properties by using run test, Shapiro-Wilk test and Predicted-versus-Residual plot, respectively. Run test revealed that the residuals are independent at 1% but not at 5% level of significance as p-value came out to be 0.042. The Shapiro-Wilk test statistic was not significant with p-value of 0.743 indicating presence of normality. However, the Predicted-versus-Residual plot given in Fig. 3 indicated presence of heteroscadasticity as is visible by a clear zig-zag pattern. Hence the above results have to be interpreted keeping presence of non-constant error varianceinto consideration and hence further data and/ or improved models need be employed for in-depth study and application.

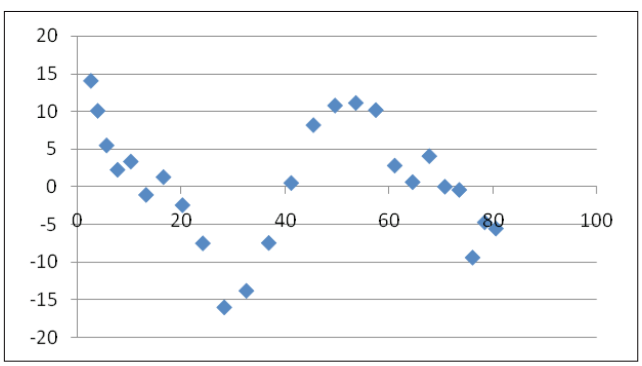

Fig. 3. Predicted-versus-Residual plot for Gompertz model (residuals on vertical axis)

It is pertinent to note here that the Kane's simulation model given in equation (1) also behaves as belonging to the 'S' shaped family of models. This can be inferred by taking a cross impact matrix of *vannamei* shrimp substitution (Table 8) by assuming that, this new technology started diffusing in the system with a very small 5% adoption rate in the late 1970s. The plot obtained is given in Fig. 4.

Table 8. Cross impact matrix of vannamei shrimp (new technology) on other shrimp species (old technology)

↙	Present level	Impact of one technology on another [*Direction of impact is indicated on the left]*	
		***Vannamei* shrimp (New technology)**	**Other shrimp species (Old technology)**
Vannamei shrimp (New technology)	5%	0	1
Other shrimp species (Old technology)	95%	-1	0

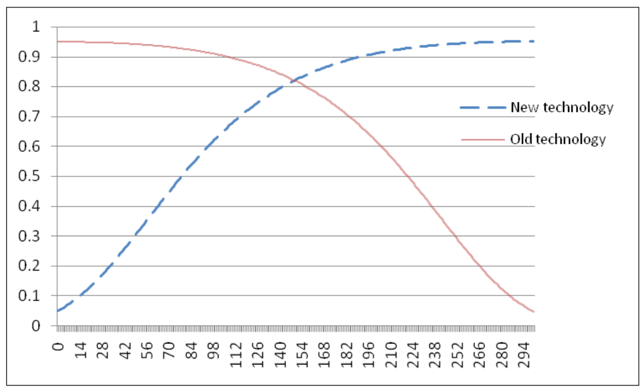

Fig 4. Kane's simulation model curve belonging to S shaped family of models

Fig. 4 reveals that Kane's simulation model also belongs to the usual elongated S curve models like Pearl, Gompertz, monomolecular and hence their general form Richards etc. It can also be seen that the depiction is analogous to the Prey-Predator competition (taking old and new technologies as prey and predator respectively) model such as Lotka-Volterra model available in the literature.

4. CONCLUSIONS

It can be concluded from substitution model fitting that the future shrimp scenario is akin tomono-cropping and bound to be affected by diseases in epidemic proportions. Application of CIA technique in production and trade scenario context of fisheries points to penaeid shrimp production overtaking other species of marine fish production in the long run. Thus, it has been demonstrated that TF can give incisive insights that can aid decision makers to plan strategies in transforming expected outcomes to desirable futures.

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